Quantum Electronic Device Simulation in Two-Dimensions

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The objective of this work is to create a general purpose quantum device simulator capable of computing electric current through nanoscale transistors and molecules. Our code utilizes a fully quantum mechanical approach which is fundamentally different from the traditional approaches adopted in industry.

Successful advancement of solid-state electronics for the last 30 years has been a result of the constant miniaturization of its building blocks—transistors and diodes. Smaller transistors will perform faster and consume less power, which will make electronics, containing millions of such transistors, better and cheaper. It is not clear however whether the functionality of nanoscale (one billionth of a meter) transistors will remain at the same level. Although it is projected that production of nanoscale transistors will begin in 5 to 10 years, there is no theoretical proof that such devices will actually perform better. The reason for this uncertainty is the onset of the quantum mechanical nature of electrons. Commercial simulators, all of which are based on classical laws of physics, fail to predict electric current correctly when transistor size becomes less than 0.1 micron. Thus a new approach is needed.

In the quantum mechanical approach, electrons form minibands of allowed energy, each acting as a path along which an electron can travel. In real space, which affects electric current, these minibands (fig. 1) are bent. Such a behavior is due to the effect of quantum confinement. Figure 2 shows how the electron flow is squeezed in the channel of the nanoscale field-effect transistor. It is the formation of the minibands and their behavior under applied electric bias that is a key to an understanding of the physics of a nanoscale transistor; that was missing in all previous work in this area.

An important consideration in the design of small transistors is standby power losses. The probabilistic nature of electrons allows them to tunnel through a huge barrier, something that never happens in the classical world. As it turns out, tunneling is a primary reason for parasitic currents flowing through a tiny transistor even when it is turned off. By using our simulator, we were able to design a better transistor and achieved an order-of-magnitude decrease of leakage without compromising overall device performance.

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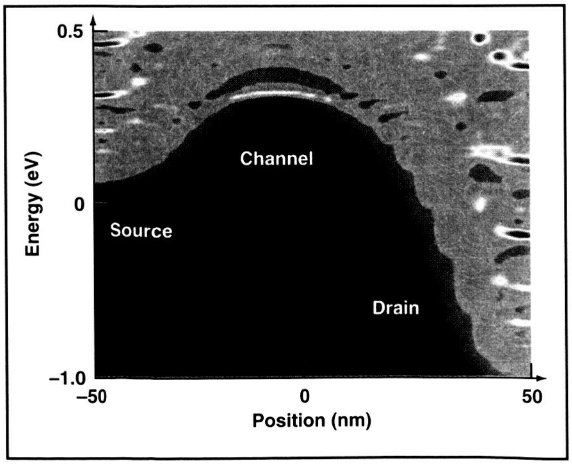

Fig. 1. Density of electron states in nanoscale field-effect transistor as a function of position and energy. Bright stripes in the middle show a formation of minibands of energy in the channel.

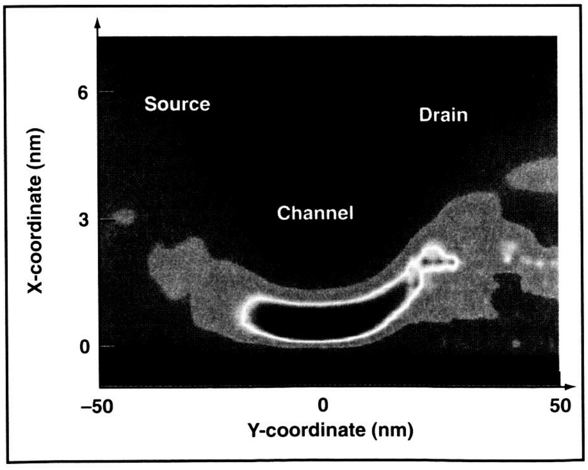

Fig. 2. Electric current flow as a function of position. Electrons are confined to a small region in the channel.